

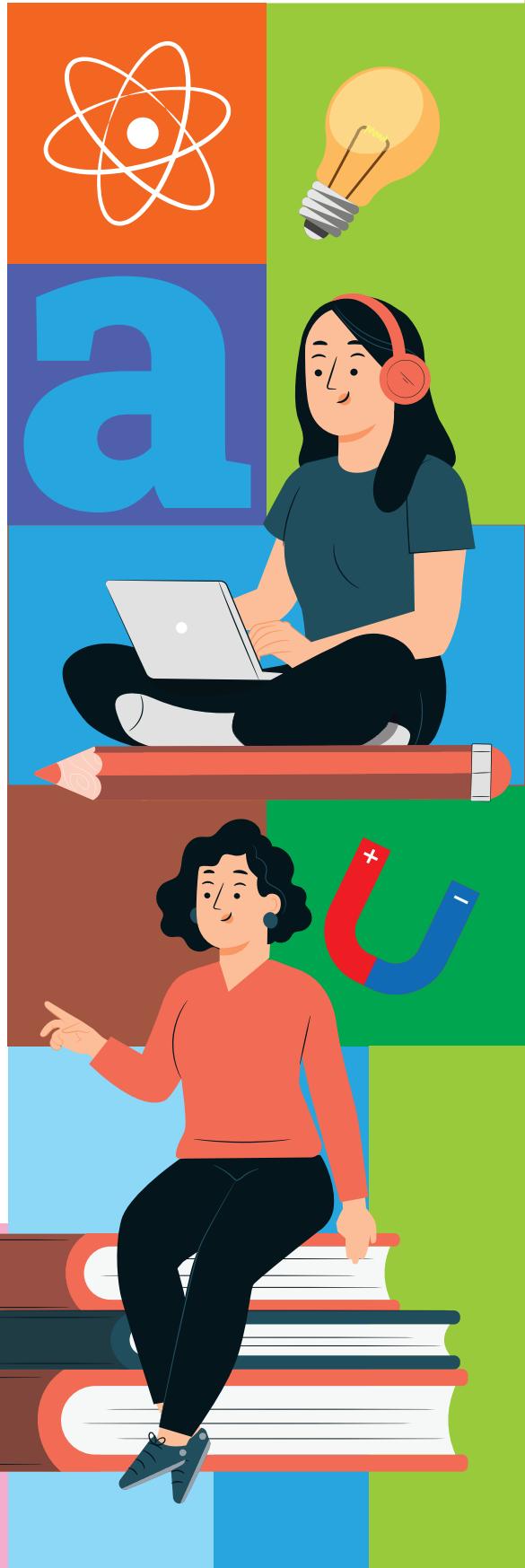


PREVIOUS YEAR QUESTION PAPERS WITH SOLUTIONS

CLASS **12**
PHYSICS

**CHAPTER WISE
TOPIC WISE
SOLVED PAPERS**

From 2014 to 2024





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Class 12 Physics

Previous Year Questions

Chapter-2 : Electrostatic Potential and Capacitance

1. ELECTROSTATIC POTENTIAL

Objective Qs (1 mark)

1. Which of the following is NOT the property of equipotential surface?

- (a) They do not cross each other.
- (b) The rate of change of potential with distance on them is zero.
- (c) For a uniform electric field they are concentric spheres.
- (d) They can be imaginary spheres.

[CBSE SQP 2023]

2. Equipotential surfaces:

- (a) are closer in regions of large electric fields compared to regions of lower electric fields.
- (b) will be more crowded near sharp edges of a conductor.
- (c) will never be equally spaced.
- (d) both (a) and (b) are correct.

[Delhi Gov. SQP 2022]

3. The electric potential on the axis of an electric dipole at a distance ' r ' from its centre is V . Then the potential at a point at the same distance on its equatorial line will be:

- (a) $2V$
- (c) $\frac{V}{2}$
- (b) $-V$
- (d) Zero

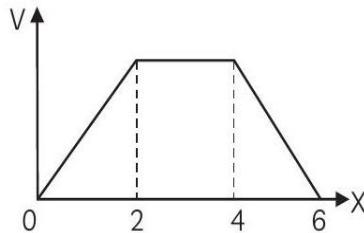
[CBSE SQP 2022]

4. If a unit positive charge is taken from one point to another over an equipotential surface:

- (a) work is done on the charge
- (b) work is done by the charge
- (c) work done is constant
- (d) no work is done

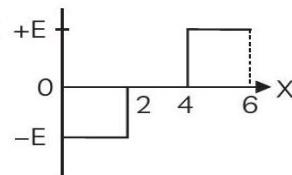
[Delhi Gov. SQP 2022]

5. The electric potential V as a function of distance X is shown in the figure.

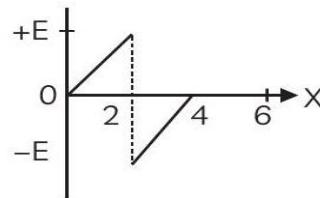


The graph of the magnitude of electric field intensity E as a function of X is:

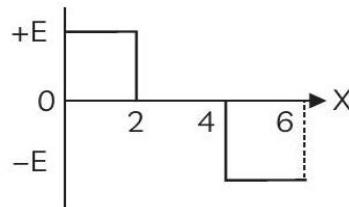
(a)



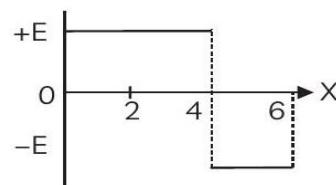
(b)



(c)



(d)



[CBSE SQP 2022]

6. The electric potential V at any point (x, y, z) is given by $V = 3x^2$ where x is in metres and V in volts. The electric field at the point $(1 \text{ m}, 0.2 \text{ m})$ is:

- (a) 6 V/m along $(-x)$ -axis
- (b) 6 V/m along $(+x)$ -axis
- (c) 1.5 V/m along $(-x)$ -axis
- (d) 1.5 V/m along $(+x)$ -axis

[CBSE Term-1 2021]

7. An electric dipole of moment p is placed parallel to the uniform electric field. The amount of work done in rotating the dipole by 90° is:

- $2pE$
- pE
- $\frac{pE}{2}$
- zero

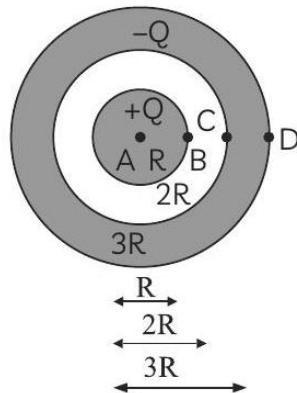
[CBSE SQP Term-1 2021]

8. Three charges $2q$, $-q$ and $-q$ lie at vertices of a triangle. The value of E and V at centroid of triangle will be:

- $E \neq 0$ and $V \neq 0$
- $E = 0$ and $V = 0$
- $E \neq 0$ and $V = 0$
- $E = 0$ and $V \neq 0$

[CBSE SQP Term-1 2021]

9. A solid spherical conductor has charge $+Q$ and radius R . It is surrounded by a solid spherical shell with charge $-Q$, inner radius $2R$, and outer radius $3R$.



Which of the following statements is true?

- The electric potential has a maximum magnitude at C and the electric field has a maximum magnitude at A.
- The electric potential has a maximum magnitude at D and the electric field has a maximum magnitude at B.
- The electric potential at A is zero and the electric field has a maximum magnitude at D.
- Both the electric potential and electric field achieve a maximum magnitude at B.

[CBSE SQP Term-1 2021]

10. Two charges $14\mu\text{C}$ and $-4\mu\text{C}$ are placed at $(-12 \text{ cm}, 0, 0)$ and $(12 \text{ cm}, 0, 0)$ in an external electric field, $\mathbf{E} = \left(\frac{\mathbf{B}}{r^2}\right)$, where $\mathbf{B} = 1.2 \times 10^6 \text{ N/cm}^2$ and r is in metres.

The electrostatic potential energy of the configuration is:

- (a) 97.9 J
- (b) 102.1 J
- (c) 2.1 J
- (d) -97.9 J

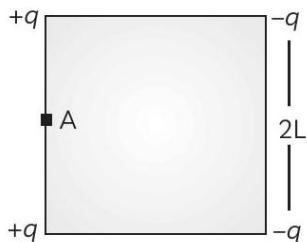
[CBSE Term-1 2021]

11. Equipotentials at a large distance from a collection of charges whose total sum is not zero are:

- (a) spheres
- (b) planes
- (c) ellipsoids
- (d) paraboloids

[CBSE Term-1 2021]

12. Four charges $-q$, $-q$, $+q$ and $+q$ are placed at the corners of a square of side $2L$ as shown in figure. The electric potential at point A midway between the two charges $+q$ and $+q$ is:



(a) $\frac{1}{4\pi\epsilon_0} \frac{2q}{L} \left(1 - \frac{1}{\sqrt{5}}\right)$ (b) $\frac{1}{4\pi\epsilon_0} \frac{2q}{L} \left(1 + \frac{1}{\sqrt{5}}\right)$

(c) $\frac{1}{4\pi\epsilon_0} \frac{q}{L} \left(1 - \frac{1}{\sqrt{5}}\right)$ (d) zero

[CBSE Term-1 2021]

For Questions 13-14, two statements are given -one labelled Assertion (A) and other labelled Reason (R). Select the correct answer to these questions from the options as given below.

- (a) If both Assertion and Reason are true and Reason is correct explanation of Assertion.
- (b) If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
- (c) If Assertion is true but Reason is false.
- (d) If both Assertion and Reason are false.

13. Assertion (A): An electron has a higher potential energy when it is at a location associated with a more negative value of potential, and a low potential energy when at a location associated with a more positive potential.

Reason (R): Electrons move from a region of higher potential to region of lower potential.

[CBSE SQP 2023]

#~~2~~ Two charges $+q$ each are kept $2a$ distance apart. A third charge $-2q$ is placed midway between them. The potential energy of the system is -

- (a) $\frac{q^2}{8\pi\epsilon_0 a}$
- (b) $-\frac{6q^2}{8\pi\epsilon_0 a}$
- (c) $-\frac{7q^2}{8\pi\epsilon_0 a}$
- (d) $\frac{9q^2}{8\pi\epsilon_0 a}$

(2024)

#~~2~~ Two identical small conducting balls B_1 and B_2 are given -7 pC and $+4$ pC charges respectively. They are brought in contact with a third identical ball B_3 and then separated. If the final charge on each ball is -2 pC, the initial charge on B_3 was:

- (a) -2 pC
- (b) -3 pC
- (c) -5 pC
- (d) -15 pC

(2024)

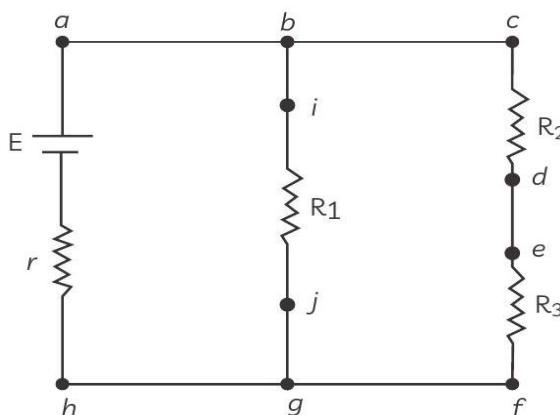
16. Assertion (A): Work done in moving a charge around a closed path, in an electric field is always zero.

Reason (R): Electrostatic force is a conservative force.

[CBSE 2023]

17. An experiment was set up with the circuit diagram shown in figure.

Given that $R_1 = 10\Omega$, $R_2 = R_3 = 5\Omega$, $r = 0\Omega$ and $E = 5$ V



(A) The points with the same potential are:

- (a) b, c, d
- (b) f, h, j
- (c) d, e, f
- (d) a, b, j

(B) The current through branch bg is:

- (a) 1 A
- (b) $\frac{1}{3}$ A
- (c) $\frac{3}{2}$ A
- (d) $\frac{2}{3}$ A

(C) The power dissipated in R_1 is:

- (a) 2 W
- (b) 2.5 W
- (c) 3 W
- (d) 4.5 W

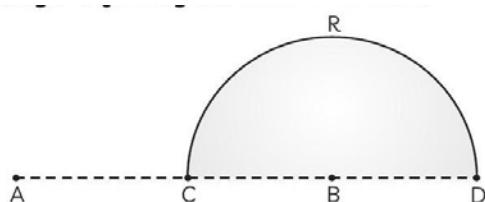
(D) The potential difference across R_3 is:

- (a) 1.5 V
- (b) 2 V
- (c) 2.5 V
- (d) 3 V

[CBSE Term-2 2021]

Very Short & Short Qs (1-3 marks)

18. Charges $(+q)$ and $(-q)$ are placed at the points A and B respectively, which are at distance $2L$ apart. C is the midpoint between A and B . What is the work done in moving a charge $+Q$ along the semicircle CRD.



[CBSE SQP 2023]

19. Two charges $5 \times 10^{-8} \text{ C}$ and $-3 \times 10^{-8} \text{ C}$ are located 16 cm apart. At what point P (lies somewhere in between the charges) on the line joining the two charges is the electric potential zero? Take the potential at infinity to be zero.

[Delhi Gov. SQP 2022]

20. The physical quantity having SI unit $\text{NC}^{-1} \text{ m}$ is

[CBSE 2020]

21. Find the expression for the potential energy of a system of two point charges q_1 and q_2 located at system r_1 and r_2 , respectively in an external electric field E .

[CBSE 2020]

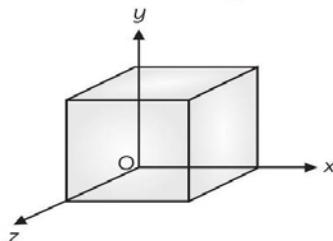
22. (A) Two point charges $+Q_1$ and $-Q_2$ are placed r distance apart. Obtain the expression for the amount of work done to place a third charge Q_3 at the midpoint of the line joining the two charges.

(B) At what distance from charge $+Q_1$ on the line joining the two charges (in terms of Q_1 , Q_2 and R) will this work done be zero.

[CBSE 2020]

23. A cube of side 20 cm is kept in a region as shown in the figure. An electric field E exists in the region such that the potential at a point is given by $V = 10x + 5$, where V is in volt and x is in m . Find the:

(A) electric field E and,
(B) total electric flux through the cube



[CBSE 2020]

24. Write two important characteristics of equipotential surfaces.

[CBSE 2020]

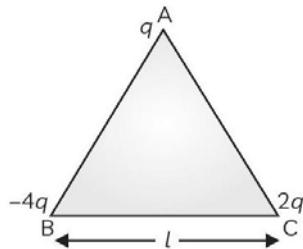
25. Draw equipotential surfaces due to an isolated point charge ($-q$) and depict the electric field lines

[CBSE 2020]

26. (A) Draw the equipotential surfaces corresponding to a uniform electric field in the z -direction.

(B) Derive an expression for the electric potential at any point along the axial line of an electric dipole.

27. (A) Three point charges q , $-4q$ and $2q$ are placed at the vertices of an equilateral triangle ABC of side l as shown in the figure. Obtain an expression for the magnitude of the resultant electric force acting on the charge q .

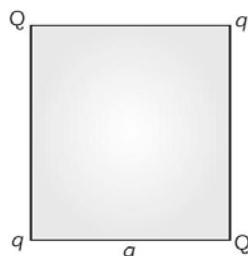


(B) Find out the amount of the work done to separate the charges at infinite distance.

[CBSE 2018]

28. Four point charges Q , q , Q and q are placed at the corners of a square of side a as shown in figure. Find the:

(A) resultant electric force on a charge Q , and
(B) potential energy of this system.



[CBSE 2018]

29. Derive the expression for the electric potential due to an electric dipole at a point on its axial line.

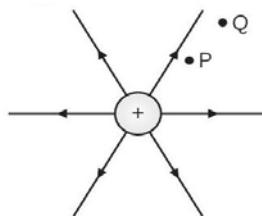
[CBSE 2017]

30. Define an equipotential surface. Draw equipotential surfaces:

(A) in the case of a single point charge and
(B) in a constant electric field in Z - direction. Why the equipotential surface about a single charge are not equidistant?
(C) Can electric field exist tangential to an equipotential surface? Give reason.

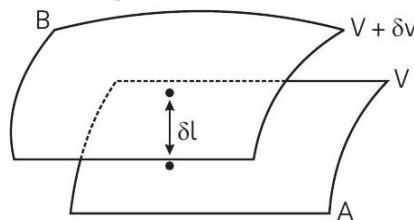
[CBSE 2016]

31. Figure shows the field lines on a positive charge. Is the work done by the field in moving a small positive charge from Q to P positive or negative? Give reason.



[CBSE 2014]

32. Two closely spaced equipotential surfaces A and B with potentials V and $V + \delta V$, (where δV is the change in V , are kept δl distance apart as shown in the figure. Deduce the relation between the electric field and the potential gradient between them. Write the two important conclusions concerning the relation between the electric field and electric potentials.



[CBSE 2014]

33. Two point charges q and $-2q$ are kept d distance apart. Find the location of the point relative to charge q at which potential due to this system of charges is zero.

[CBSE 2014]

34. Obtain an expression for the electric potential due to a small dipole of dipole moment \vec{P} , at a point r from its centre, for much larger distances compared to the size of the dipole.

(2024)

35. Three point charges q , $2q$ and nq are placed at the vertices of an equilateral triangle. If the potential energy of the system is zero, find the value of n .

(2024)

2. ELECTROSTATIC OF CONDUCTORS, DIELECTRICS AND CAPACITANCE

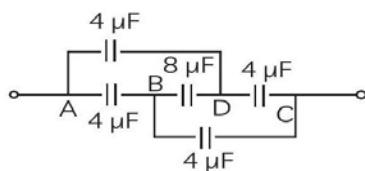
Objective Qs (1 mark)

36. When a dielectric material is introduced between the plates of a charged condenser, then electric field between the plates:

- (a) decreases
- (b) remains constant
- (c) increases
- (d) first increases then decreases

[Delhi Gov. SQP 2022]

37.



In the given figure equivalent capacitance of the given combination of five capacitors is:

- (a) $4\mu\text{F}$
- (b) $10\mu\text{F}$
- (c) $8\mu\text{F}$
- (d) $120\mu\text{F}$

[Delhi Gov. SQP 2022]

38. When air is replaced by a dielectric medium of dielectric constant K the force of attraction between two charges Q_1 and Q_2 separated by a finite distance d :

- (a) decreases K times
- (b) increases K times
- (c) remains unchanged
- (d) decreases $2K$ time

[Delhi Gov. SQP 2022]

39. Two parallel plate capacitors X and Y , have the same area of plates and same separation between plates. X has air and Y with dielectric of constant 2, between its plates. They are connected in series to a battery of 12 V. The ratio of electrostatic energy stored in X and Y is:

- (a) 4: 1
- (b) 1: 4
- (c) 2: 1
- (d) 1: 2

[CBSE SQP Term-1 2021]

40. A capacitor plates are charged by a battery with ' V ' volts. After charging battery is disconnected and a dielectric slab with dielectric constant ' K ' is inserted between its plates, the potential across the plates of a capacitor will become:

- (a) zero
- (b) $\frac{V}{2}$
- (c) $\frac{V}{K}$
- (d) KV

[CBSE SQP Term-1 2021]

41. A car battery is charged by a 12 V supply, and energy stored in it is 7.20×10^5 J. The charge passed through the battery is:

- (a) 6.0×10^4 C
- (b) 5.8×10^3 J
- (c) 8.64×10^6 J
- (d) 1.6×10^5 C

[CBSE Term-1 2021]

42. A variable capacitor is connected to a 200 V battery. If its capacitance is changed from $2\mu\text{F}$ to $X\mu\text{F}$, the decrease in energy of the capacitor is 2×10^{-2} J. The value of X is:

- (a) $1\mu\text{F}$
- (b) $2\mu\text{F}$
- (c) $3\mu\text{F}$
- (d) $4\mu\text{F}$

[CBSE Term-1 2021]

Very Short & Short Qs (1 - 3 marks)

43. Two charged conducting spheres of radii a and b are connected to each other by a wire. Find the ratio of the electric fields at their surfaces.

[CBSE 2020]

44. A parallel plate capacitor (A) of capacitance C is charged by a battery to voltage V . The battery is disconnected and an uncharged capacitor (B) of capacitance $2C$ is connected across A. Find the ratio of:

(A) final charges on A and B .

(B) total electrostatic energy stored in A and B finally and that stored in A initially.

[CBSE 2023]

45. (A) Draw equipotential surfaces for (i) an electric dipole and (ii) two identical positive charges places near each other.

(B) In a parallel plate capacitor with air between the plates each plate has an area of $6 \times 10^{-3} \text{ m}^2$ and the separation between the plates is 3 mm.

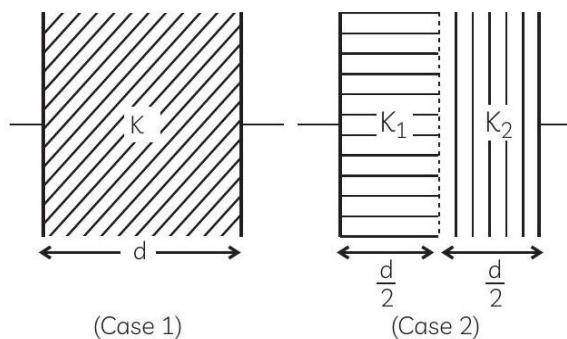
(i) Calculate the capacitance of the capacitor.

(ii) If the capacitor is connected to 100 V supply, what would be the charge on each plate?

(iii) How would charge on the plate be affected if a 3 mm thick mica sheet of $K = 6$ is inserted between the plates while the voltage supply remains connected?

[CBSE SQP 2022]

46. The space between the plates of a parallel plate capacitor is completely filled in two ways. In the first case, it is filled with a slab of dielectric constant K . In the second case, it is filled with two slabs of equal thickness and dielectric constants K_1 and K_2 respectively as shown in the figure. The capacitance of the capacitor is same in the two cases. Obtain the relationship between K, K_1 and K_2 .



[CBSE 2020]

47. When a parallel plate capacitor is connected across a dc battery, explain briefly how the capacitor gets charged.

[CBSE 2019]

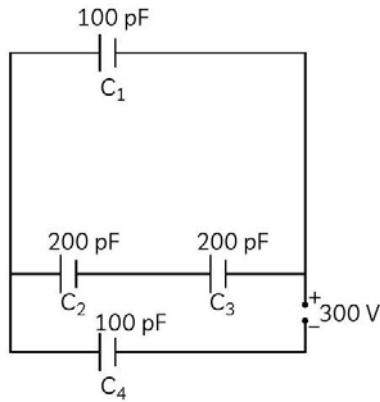
48. A parallel plate capacitor is charged by a battery to a potential difference V . It is disconnected from battery and then connected to another uncharged capacitor of the same capacitance. Calculate the ratio of the energy stored in the combination to the initial energy on the single capacitor.

[CBSE 2019]

49. (A) Derive an expression for the capacitance of a parallel plate capacitor with air present between the two plates.

(B) Obtain the equivalent capacitance of the network shown in figure. For a 300 V supply, determine the charge on each capacitor.

[Delhi Gov. SQP 2022]



[CBSE SQP 2023]

50. A parallel plate capacitor of capacitance ' C ' is charged to ' V ' volts by a battery. After some time the battery is disconnected and the distance between the plates is doubled. Now a slab of dielectric constant, $1 \leq k < 2$, is introduced to fill the space between the plates. How will the following be affected?

- (A) The electric field between the plates of the capacitor
- (B) The energy stored in the capacitor
- (C) Justify your answer by writing the necessary expressions.

[CBSE 2019]

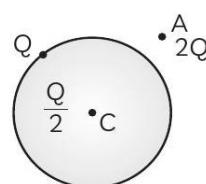
51. Derive an expression for the energy stored in a parallel plate capacitor. On charging a parallel plate capacitor to a potential V , the spacing between the plates is halved and a dielectric medium of $\epsilon_r = 10$ is introduced between the plates. Explain, using suitable expression, how the (A) capacitance, (B) electric field.

[CBSE 2018]

52. An infinitely large thin plane sheet has a uniform surface charge density $+\sigma$. Obtain the expression for the amount of work done in bringing a point charge q from infinity to a point, distant r , in front of the charged plane sheet.

[CBSE 2017]

53. (A) Explain, using suitable diagrams, the difference in the behaviour of a (i) conductor and (ii) dielectric in the presence of external electric field. Define the terms polarisation of a dielectric and write its relation with susceptibility.
 (B) A thin metallic spherical shell of radius R carries a charge Q on its surface. A point charge $\frac{Q}{2}$ is placed at its centre C and an other charge $+2Q$ is placed outside the shell at a distance x from the centre as shown in the figure. Find (i) the force on the charge at the centre of shell and at the point A , (ii) the electric flux through the shell.



[CBSE 2015]

54. Two capacitors of unknown capacitances C_1 and C_2 are connected first in series and then in parallel across a battery of 100 V. If the energy stored in the two combinations is 0.045 J and 0.25 J respectively, then determine the value of C_1 and C_2 . Also, calculate the charge on each capacitor in parallel combination.

[CBSE 2015]

Numerical Qs (1 - 5 marks)

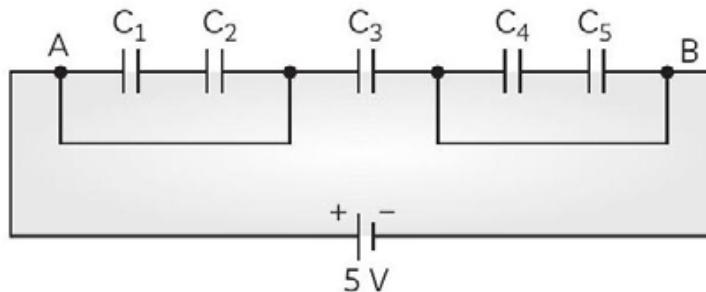
55 In the figure given below, find the

(A) equivalent capacitance of the network between points A and B .

Given: $C_1 = C_5 = 4\mu F$, $C_2 = C_3 = C_4 = 2\mu F$.

(B) maximum charge supplied by the battery, and

(C) total energy stored in the network.

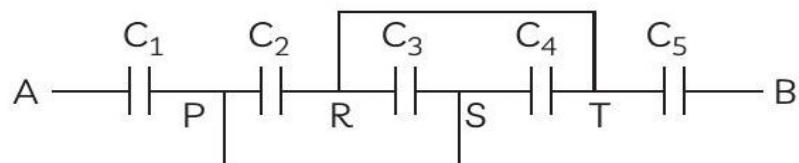


[CBSE 2020]

56. Two identical capacitors of 12pF each are connected in series across a battery of 50 V. How much electrostatic energy is stored in the combination? If these were connected in parallel across the same battery, how much energy will be stored in the combination now? Also find the charge drawn from the battery in each case.

[CBSE 2017]

57. (A) Find equivalent capacitance between A and B in the combination given below. Each capacitor is of $2\mu F$ capacitance.



(B) If a dc source of 7 V is connected across AB , how much charge is drawn from the source and what is the energy stored in the network?

[CBSE 2017]

Energy Stored in a Capacitor:

MCQ:

58. Ten capacitors, each of capacitance $1 \mu\text{F}$, are connected in parallel to a source of 100 V . The total energy stored in the system is equal to :

- (a) 10^{-2}
- (b) 10^{-3}
- (c) 0.5×10^{-3}
- (d) 5.0×10^{-2}

(2024)



Class 12 Physics
PYQ (Solution)

**Chapter-2 : Electrostatic Potential and
Capacitance**

1. ELECTROSTATIC POTENTIAL

1. (c) For a uniform electric field, they are concentric spheres.

Explanation: As all other statements are correct. In uniform electric field equipotential surfaces are never concentric spheres but are planes perpendicular to electric field lines.

2. (d) both (a) and (b) are correct.

Explanation: Electric field $E = -\frac{dV}{dr}$

dr is inversely proportional to electric field.

Equipotential surfaces are closer in regions of large electric fields compared to regions of lower electric field. At sharp edges of a conductor, charge density is more. Therefore, electric field is stronger. Hence, equipotential surfaces are more crowded.

3. (d) Zero

Explanation: For equatorial line, $\theta = 90^\circ$

For axial line $\theta = 0$

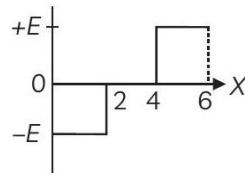
$$V = \frac{kp}{r^2} \cos \theta$$
$$V = \frac{kp}{r^2}$$

For equatorial line, $V = 0$ as $\cos 90^\circ = 0$

4. (d) no work is done

Explanation: Since the potential at each point of an equipotential surface is the same, the potential does not change while we move a unit positive charge from one point to another. Therefore, work done in the process is zero.

5. (a)



Explanation:

$$E = -\frac{dV}{dx}$$

For 0 – 2 seconds, $\frac{dV}{dx} = +ve$ and constant

So, $E = -ve$ and constant

For 2 – 4 seconds, $\frac{dV}{dx} = 0$

So, $E = 0$

For 4 – 6 seconds, $\frac{dV}{dx} = -ve$ and constant

So, $E = +ve$ and constant

6. (a) 6 V/m along (-X)-axis

Explanation:

$$E_x = -\frac{dV}{dx} = -6x$$

$$E_z = -\frac{dV}{dz} = 0$$

As the electric field is only changing in negative x -direction, $E = 6 \times 1 = 6$ V/m along $(-x)$ axis.

7. (b) pE

Explanation:

$$W = pE(\cos \theta_1 - \cos \theta_2)$$

$$\theta_1 = 0^\circ$$

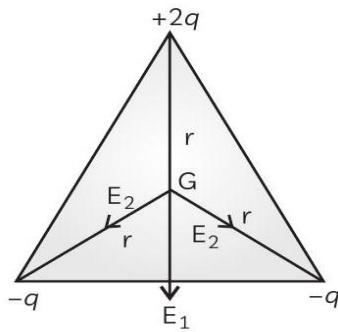
$$\theta_2 = 90^\circ$$

$$W = pE(\cos 0^\circ - \cos 90^\circ)$$

$$= pE(1 - 0) = pE$$

8. (c) $E \neq 0$ and $V = 0$

Explanation:



Net electric field intensity at $G \neq 0$ Net Potential at G ,

$$V = \frac{k2q}{r} - \frac{Kq}{r} - \frac{Kq}{r}$$

$$V = 0$$

9. (d) Both the electric potential and electric field achieve a maximum magnitude at B .

Explanation: Electric potential, $V \propto \frac{1}{R}$.

Hence, at B it achieves maximum value as value of potential will be equal on the whole conductor.

Similarly, electric field $E \propto \frac{1}{R^2}$ and also attains maximum value at B as field inside conductor is zero.

10. (b) 102.19

$$U = k \frac{q_1 q_2}{r} + q_1 V + q_2 V$$

$$V = - \int E \cdot dr$$

$$V = \frac{B}{r}$$

Explanation: $= \frac{1.2 \times 10^6}{24 \times 10^{-2}}$
 $= 5 \times 10^6 \text{ V.}$

$$U = 9 \times 10^9 \times \frac{14 \times (-4) \times 10^{-12}}{24 \times 10^{-2}}$$

$$+ (14 \times 10^{-6}) \times (5 \times 10^6)$$

$$+ (-4 \times 10^{-6}) \times (5 \times 10^6)$$

$$U = 102.1 \text{ J}$$

11. (a) spheres

Explanation: A collection of charges located at a very large distance can be considered as the point charge. Now, in all directions, the equipotential surface for a point charge will be at the same distance from the point. As a result, the surface of the equipotential points for a point charge will be spherical.

12. (A) (a) $\frac{1}{4\pi\epsilon_0} \frac{2q}{L} \left(1 - \frac{1}{\sqrt{5}}\right)$

Explanation:

Solving,

$$\begin{aligned}V_A &= V_1 + V_2 + V_3 + V_4 \\&= \frac{1}{4\pi\epsilon_0} \left[\frac{q}{L} + \frac{q}{L} - \frac{q}{\sqrt{5}L} - \frac{q}{\sqrt{5}L} \right]\end{aligned}$$

we get,

$$V_A = \frac{1}{4\pi\epsilon_0} \frac{2q}{L} \left(1 - \frac{1}{\sqrt{5}} \right)$$

13. (c) If Assertion is true but Reason is false.

Explanation: We know that,

$$U = q V$$

where, V is potential and U is potential energy. As electron has a negative charge, the higher negative potential and negative charged electron will give maximum potential energy.

$$\begin{aligned}U &= (-e)(-V) \\&= eV = \text{maximum}\end{aligned}$$

Current flows from higher potential to lower potential and electron flows in opposite to the current. Hence, electrons flow from lower to higher potential.

14. (C) $\frac{-7q^2}{8\pi\epsilon_0 a}$ (2024)

15. (B) -3 pC

16. (a) If both Assertion and Reason are true and Reason is the correct explanation of Assertion

Explanation: According to this statement, the work done in moving a charge around a closed path, in an electric field, is always zero. This is because the electric field is a conservative field, which means that the work done in moving a charge between two points in the field is independent of the path taken by the charge. Reason R is also true. The electrostatic force is a conservative force. This means that the work done by the electrostatic force on a charge moving between two points in an electric field is independent of the path taken by the charge.

17. (A) (b) f, h, j

Explanation: g and j are at same potential as there is no cell or circuit element between them. Also, g, h and f are also at same potential so we can say, f, h and j are at same potential.

(B) (c) $\frac{1}{2} A$

Explanation: The total current in the circuit $I = \frac{E}{R}$ as $r = 0$. Here R is the equivalent resistance of the circuit. The equivalent resistance of branch cf is $R_2 + R_3 = 10\Omega$. So, equivalent resistance of circuit,

$$R = \frac{10 \times 10}{20} = 5\Omega$$

The total current in the circuit, $I = \frac{5}{5} = 1$ A.

Current in branch $bg = \frac{E}{10} = \frac{5}{10} = \frac{1}{2}$ A.

(C) (b) 2.5 W

Explanation: Power dissipated in R_1 ,

$$\begin{aligned} P_1 &= I_1^2 R_1 \\ &= \frac{1}{4} \times 10 \\ &= 2.5 \text{ W.} \end{aligned}$$

(D) (c) 2.5 V

Explanation: Current in branch cf,

$$\begin{aligned} I_2 &= I - I_1 \\ &= 0.5 \text{ A.} \end{aligned}$$

Hence, voltage drop across R_3 ,

$$\begin{aligned} V_3 &= I_2 R_3 \\ &= 0.5 \text{ A} \times 5\Omega \\ &= 2.5 \text{ V.} \end{aligned}$$

(2024)

18.

$$\begin{aligned} V_C &= 0, \\ V_D &= \frac{1}{4\pi\epsilon_0} \left[\frac{q}{3L} - \frac{q}{L} \right] \\ &= \frac{-q}{6\pi\epsilon_0 L} \\ W &= Q[V_D - V_C] = \frac{-Qq}{6\pi\epsilon_0 L} \end{aligned}$$

19. Let P be the point of zero potential at distance r from the charge q_1 .

$$d = 16 \text{ cm}$$

$$\text{Electric potential, } V = \frac{q_1}{4\pi\epsilon_0 r} + \frac{q_2}{4\pi\epsilon_0 (d-r)}$$

$$\text{For } V = 0,$$

$$\frac{q_1}{r} = -\frac{q_2}{d-r}$$

$$\Rightarrow \frac{5 \times 10^{-8}}{r} = \frac{-3 \times 10^{-8}}{0.16-r}$$

$$r = 10 \text{ cm}$$

So, the point will be 10 cm from positive charge.

20. Electric Potential

21. Work done in bringing Q_1 from infinity against the electric field

$$W = q_1 V |\vec{r}_1|$$

Work done in bringing Q_2 from infinity against the electric field

$$W = q_2 V |\vec{r}_2|$$

Work done on Q_2 against the field due to Q_1

$$= \frac{q_1 q_2}{4\pi\epsilon_0 r_{12}}$$

The potential energy of the system = Total work done in assembling the system

$$= q_1 V |\vec{r}_1| + q_2 V |\vec{r}_2| + \frac{q_1 q_2}{4\pi\epsilon_0 r_{12}}$$

22. (A)

$$W_{Q_1 Q_3} = \frac{k Q_1 Q_3}{\frac{r}{2}} = 2 \frac{k Q_1 Q_3}{r}$$

$$W_{Q_2 Q_3} = - \frac{k Q_2 Q_3}{\frac{r}{2}} = -2 \frac{k Q_2 Q_3}{r}$$

$$\text{Total work} = 2 \frac{k Q_1 Q_3}{r} - 2 \frac{k Q_2 Q_3}{r}$$

$$= \frac{Q_3 (Q_1 - Q_2)}{2\pi\epsilon_0 r}$$

(B) Let x be the required distance

$$\frac{k Q_1}{x} - \frac{k Q_2}{x-r} = 0$$

$$x = \frac{Q_1 r}{Q_1 - Q_2}$$

23. Given that:

$$V = 10x + 5$$

We know,

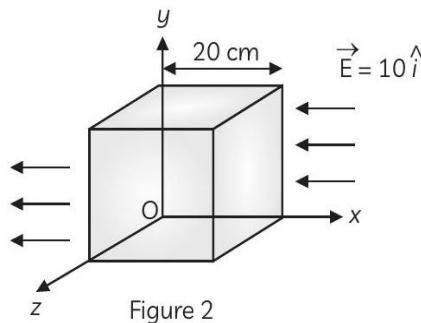
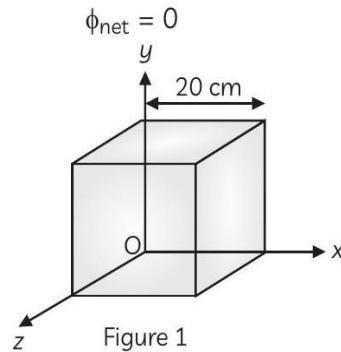
$$\begin{aligned} E &= -\frac{dv}{dx} \\ V &= 10x + 5 \\ \frac{dV}{dx} &= \frac{d}{dx}(10x + 5) \\ &= 10 \frac{d}{dx}x + 0 \\ &= 10 \\ E &= -10 \text{ N/C} \\ \vec{E} &= -10\hat{i} \text{ N/C} \end{aligned}$$

Since, electric field is constant in negative x -direction

So, flux entering in the cube will be same as flux coming out through the cube

$$\phi_{\text{in}} = \phi_{\text{out}}$$

So, Net flux from the cube = 0

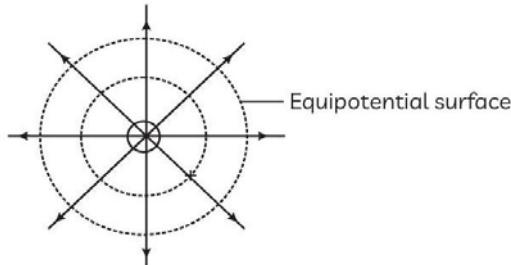


24. Equipotential surfaces have two important properties:

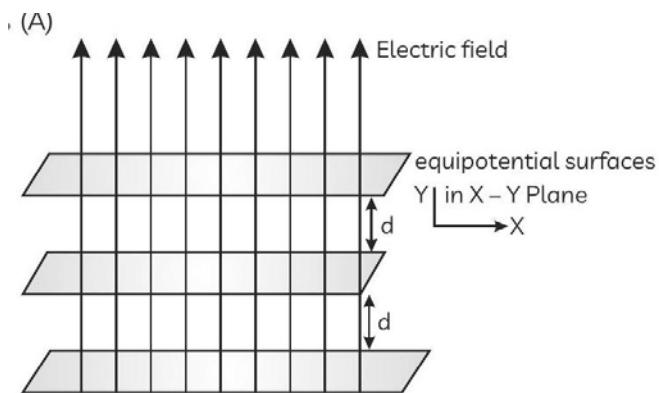
- (1) The electric field at any location on an equipotential surface is oriented normal to the equipotential surface in the direction of potential fall.

(2) At no point can two equipotential surfaces cross each other.

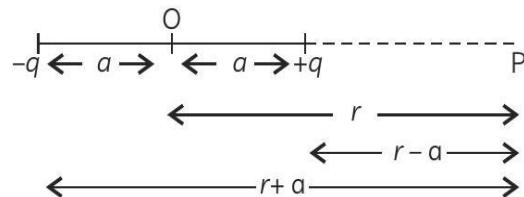
25. An equipotential surface is one that has the same electric potential at all points. Field lines are always perpendicular to equipotential surfaces. Equipotential surfaces for an isolated point charge are the surfaces of concentric spheres at the centre, as shown in the picture below:



26. (A)



(B)



Electrostatic potential at point P due to $+q$ charge

$$V_{+q} = \frac{1}{4\pi\epsilon_0} \frac{+q}{(r - a)}$$

Electrostatic potential at point P due to $-q$ charge.

$$V_{-q} = \frac{1}{4\pi\epsilon_0} \frac{-q}{(r + a)}$$

Net potential at point P according to the principle of superposition.

$$\begin{aligned}
 V_{+q} &= \frac{1}{4\pi\epsilon_0} \frac{+q}{(r+a)} \\
 V &= V_{+q} + V_{-q} \\
 V &= \frac{1}{4\pi\epsilon_0} \frac{+q}{(r-a)} + \frac{1}{4\pi\epsilon_0} \frac{-q}{(r+a)} \\
 V &= \frac{q}{4\pi\epsilon_0} \left[\frac{1}{r-a} - \frac{1}{r+a} \right] \\
 V &= \frac{q}{4\pi\epsilon_0} \left[\frac{r+a - r+a}{r^2 - a^2} \right] \\
 V &= \frac{q}{4\pi\epsilon_0} \frac{2a}{(r^2 - a^2)}
 \end{aligned}$$

Electric dipole moment, $P = q(2a)$

$$V = \frac{1}{4\pi\epsilon_0} \frac{P}{r^2 - a^2}$$

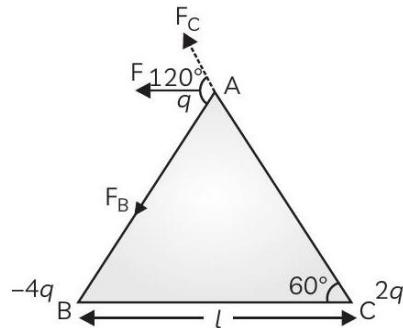
27. (A) Electric force at A due to charge $2q$

$$F_C = \frac{1}{4\pi\epsilon_0} \frac{q \times 2q}{l^2} \text{ along } \overrightarrow{CA}$$

Electric force at A due to charge $(-4q)$,

$$F_B = \frac{q \times (-4q)}{4\pi\epsilon_0 l^2} \text{ along } \overrightarrow{AB}$$

Above situation can be represented as



Now we can write

Resultant force,

$$F = \sqrt{F_B^2 + F_C^2 + 2F_B F_C \cos 120^\circ}$$

$$F = \frac{q^2}{4\pi\epsilon_0 l^2} \sqrt{(4)^2 + (2)^2 + 2(4)(2)\left(-\frac{1}{2}\right)}$$

Therefore,

$$F = \frac{\sqrt{12}q^2}{4\pi\epsilon_0 l^2}$$

(B) Work done to separate the charges to infinity is given as change in the potential Initial potential energy,

$$U = \frac{q^2}{4\pi\epsilon_0 l} \left[\frac{(-4q)q}{l} + \frac{(-4q)(2q)}{l} + \frac{(q)(2q)}{l} \right]$$

$$= \frac{q^2}{4\pi\epsilon_0 l} [-4 - 8 + 2]$$

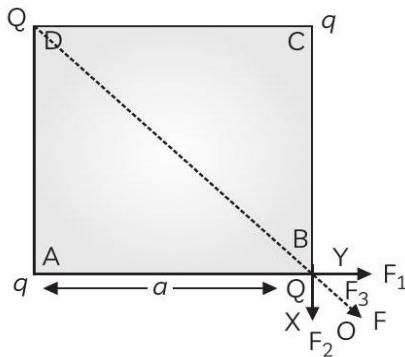
$$= \frac{1}{4\pi\epsilon_0} \left(\frac{-10q^2}{l} \right)$$

Final potential energy, $U_f = 0$

Thus, work done = $U_f - U_i = 0 - \left(\frac{-10q^2}{4\pi\epsilon_0 l} \right)$

$$= \frac{10q^2}{4\pi\epsilon_0 l}$$

28. (A) Force on charge Q at B due to charge q $F_2 = \frac{qQ}{4\pi\epsilon_0 a^2}$ along \vec{BY}



$$F_2 = \frac{qQ}{4\pi\epsilon_0 a^2} \text{ along } \vec{BX}$$

Resultant force, $F = \sqrt{F_1^2 + F_2^2}$ along \vec{BO}

$$= \sqrt{2 \left(\frac{qQ}{4\pi\epsilon_0 a^2} \right)^2} = \frac{qQ\sqrt{2}}{4\pi\epsilon_0 a^2}$$

Force due to charge $Q = F_3 = \frac{Q^2}{4\pi\epsilon_0(\sqrt{2}a^2)}$

along \overrightarrow{BO}

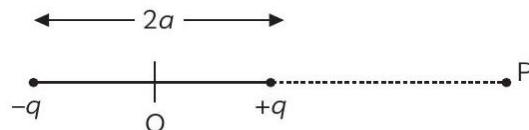
Total resultant force = $F + F_3$ along \overrightarrow{BO}

$$\begin{aligned} &= \frac{1\sqrt{2}Qq}{4\pi\epsilon_0 a^2} + \frac{Q^2}{4\pi\epsilon_0^2 a^2} \\ &= \frac{Q}{4\pi\epsilon_0 a^2} \left(\sqrt{2}q + \frac{Q}{2} \right) \text{ along } \overrightarrow{BO} \end{aligned}$$

(B) Total potential energy of the system,

$$\begin{aligned} U &= \frac{1}{4\pi\epsilon_0} \left[\frac{Qq}{a} + \frac{Qq}{a} + \frac{Qq}{a} + \frac{Qq}{a} + \frac{Qq}{a} \right. \\ &\quad \left. + \frac{QQ}{\sqrt{2}a} + \frac{qq}{\sqrt{2}a} \right] \\ &= \frac{1}{4\pi\epsilon_0} \left[\frac{4Qq}{a} + \frac{Q^2}{\sqrt{2}a} + \frac{a^2}{\sqrt{2}a} \right] \\ &= \frac{1}{4\pi\epsilon_0 a} \left[4Qq + \frac{Q^2 + q^2}{\sqrt{2}} \right] \end{aligned}$$

29.



Let P be an axial point at distance r from the center of the dipole. Electric potential at point P is given as,

$$V = V_1 + V_2$$

V_1 and V_2 are the potentials at point P due to charges $+q$ and $-q$ respectively

$$V = \frac{1}{4\pi\epsilon_0} \left(\frac{q}{r-a} + \left(\frac{-q}{r+a} \right) \right)$$

$$V = \frac{1}{4\pi\epsilon_0} \left(\frac{2a}{(r^2 - a^2)} \right)$$

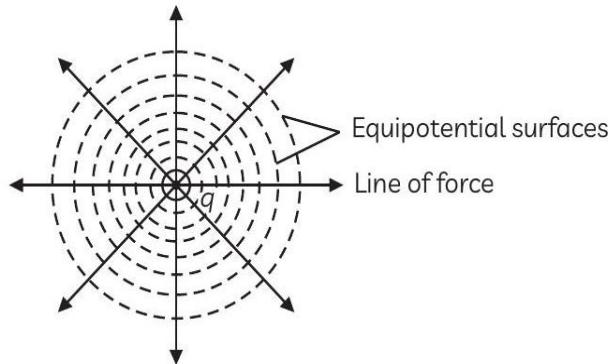
$$V = \frac{1}{4\pi\epsilon_0} \left(\frac{P}{(r^2 - a^2)} \right)$$

Hence, the electric potential is

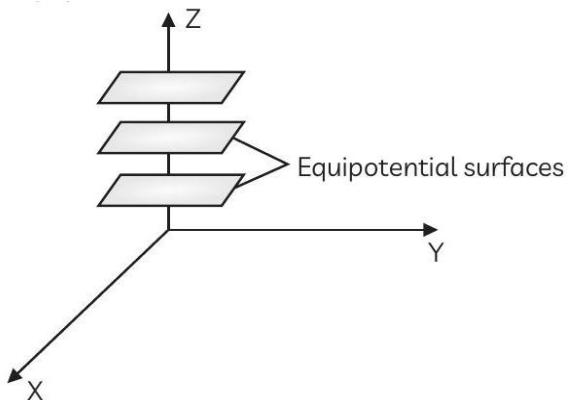
$$\frac{1}{4\pi\epsilon_0} \left(\frac{P}{(r^2 - a^2)} \right)$$

30. Equipotential surface is a surface which has equal potential at every point on it.

(A) Equipotential surfaces due to single point charge are concentric sphere having charge at the center.]



(B) In constant electric field along z-direction, the perpendicular distance between equipotential surfaces remains same.



For single charge, equipotential surface will be series of concentric spherical shells with charge at centre, $dr \propto \frac{1}{E}$ the separation dr between equipotential surface will go on increasing with decrease in electric field.

(C) No, because if there is tangential component of electric field along surface it would result in motion of electrons, but since we have static fields, this is not possible.

31. The work done by the field is negative. This is because the charge is moved against the force exerted by the field.

32. $\vec{E}_A = -\vec{\nabla}V$ and $\vec{E}_B = -\vec{\nabla}(V + \delta V)$

$$\begin{aligned}\vec{E}_B &= -\vec{\nabla}V - \vec{\nabla}(\delta V) \\ &= \vec{E}_A - \vec{\nabla}(\delta V)\end{aligned}$$

$$\text{Net field} = \vec{E}_B - \vec{E}_A = -\vec{\nabla}(\delta V)$$

(1) Electric field is perpendicular to the equipotential surfaces.

(2) Net field is also gradient of potential δV .

33. (i) When a dielectric slab is inserted between the plates of capacitor, there is induced charge density σ_P which opposes the original charge density

(σ) on the plate of capacitance.

Electric field with dielectric medium is

$$E = \frac{(\sigma - \sigma_P)}{\epsilon_0}$$

$$V = E \times d = \frac{(\sigma - \sigma_P)}{\epsilon_0} d$$

$$(\sigma - \sigma_P) = \frac{V}{d}$$

$$V = \frac{\sigma d}{\epsilon_0 K} = \frac{Qd}{A\epsilon_0 K}$$

$$C = \frac{Q}{V} = \frac{K\epsilon_0 A}{d}$$

(ii) Electric potential due to a point charge

$$V = \frac{1}{4\pi\epsilon_0} \frac{q}{r}$$

(i) At the surface

$$V = \frac{1}{4\pi\epsilon_0} \frac{q}{r} = \frac{9 \times 10^9 \times 6 \times 10^{-6}}{0.2}$$

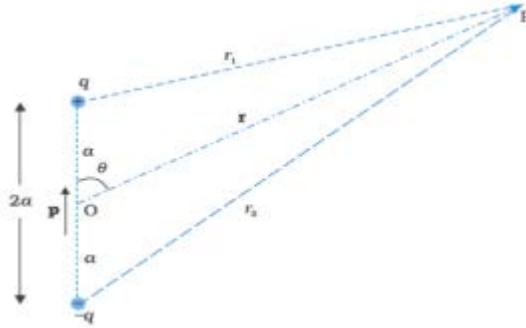
$$V = 2.7 \times 10^5 \text{ V}$$

(ii) Since electric field inside the hollow sphere is zero, hence V is same as that of the surface and remains constant throughout the volume.

$$V = 2.7 \times 10^5 \text{ V}$$

34. a)

(i)



Potential due to the dipole is the sum of potentials due to charges q and $-q$

$$V = \frac{1}{4\pi\epsilon_0} \left(\frac{q}{r_1} - \frac{q}{r_2} \right) \quad \text{--- (1)}$$

By geometry

$$\begin{aligned} r_1^2 &= r^2 + a^2 - 2ar \cos \theta \\ r_2^2 &= r^2 + a^2 + 2ar \cos \theta \end{aligned}$$

For $r \gg a$, retaining terms only up to first order in a/r

$$\begin{aligned} r_1^2 &= r^2 \left(1 - \frac{2a \cos \theta}{r} + \frac{a^2}{r^2} \right) \\ &\approx r^2 \left(1 - \frac{2a \cos \theta}{r} \right) \end{aligned}$$

Similarly

$$r_2^2 \approx r^2 \left(1 + \frac{2a \cos \theta}{r} \right)$$

Using the binomial theorem and retaining terms up to the first order in a/r

$$\begin{aligned} \frac{1}{r_1} &\approx \frac{1}{r} \left(1 - \frac{2a \cos \theta}{r} \right)^{-1/2} \\ &\approx \frac{1}{r} \left(1 + \frac{a \cos \theta}{r} \right) \quad \text{--- (2)} \end{aligned}$$

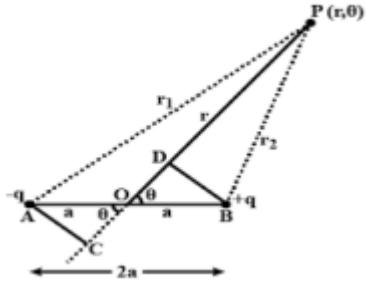
$$\begin{aligned} \frac{1}{r_2} &\approx \frac{1}{r} \left(\frac{1 + 2a \cos \theta}{r} \right)^{-1/2} \quad \text{--- (3)} \\ &\approx \frac{1}{r} \left(1 - \frac{a \cos \theta}{r} \right) \end{aligned}$$

Using eqn. (1) (2), (3) and $p = 2qa$

$$V = \frac{q}{4\pi\epsilon_0} \frac{2a \cos \theta}{r^2}$$

$$= \frac{p \cos \theta}{4\pi\epsilon_0 r^2}$$

Alternatively:



$$r_2 = r + a \cos \theta$$

$$r_1 = r - a \cos \theta$$

$$V = \frac{q}{4\pi\epsilon_0} \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$$

$$V = \frac{q}{4\pi\epsilon_0} \left(\frac{1}{r - a \cos \theta} - \frac{1}{r + a \cos \theta} \right)$$

$$= \frac{q}{4\pi\epsilon_0} \left(\frac{2a \cos \theta}{r^2 - a^2 \cos^2 \theta} \right)$$

$$= \frac{p}{4\pi\epsilon_0 r^2} \left(\frac{\cos \theta}{1 - \frac{a^2}{r^2} \cos^2 \theta} \right)$$

For $r \gg a$, neglecting $\frac{a^2}{r^2}$

$$V = \frac{p \cos \theta}{4\pi\epsilon_0 r^2}$$

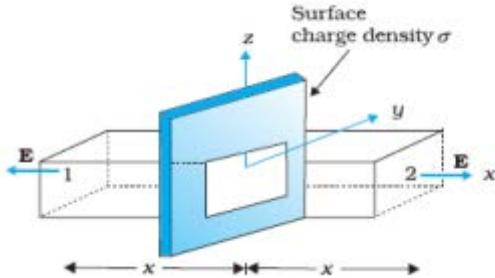
(2024)

35. (i) Electric Flux through a closed surface is equal to $\frac{q}{\epsilon_0}$, where q is the total charge enclosed by the surface. $\phi = \frac{q}{\epsilon_0}$

Alternatively The surface integral of electric field over a closed surface is $\frac{1}{\epsilon_0}$ times the total charge enclosed by the surface.

$$\oint \vec{E} \cdot d\vec{S} = \frac{q}{\epsilon_0}$$

(Award ½ mark for writing the formula only.)



(Gaussian surface can be cylindrical also) As seen from figure, only two faces 1 and 2 will contribute to the flux. Flux $E \cdot dS$ through both the surfaces is equal and add up.

The charge enclosed by surface is σA , where σ is surface charge density According to Gauss's theorem

$$2EA = \sigma A / \epsilon_0$$

$$E = \sigma / 2\epsilon_0$$

$$\vec{E} = \frac{\sigma}{2\epsilon_0} \hat{n}$$

where \hat{n} is unit vector directed normally out of the plane

$$(ii) \vec{E} = \frac{\lambda}{2\pi\epsilon_0 r} \hat{r}$$

According to question

$$E_1 \text{ (at point P)} = \frac{\lambda_1}{2\pi\epsilon_0 r_1}$$

$$\vec{E} = \frac{10 \times 10^{-6}}{2\pi\epsilon_0 (10 \times 10^{-2})} (-\hat{j}) \text{ N/C}$$

$$E_2 \text{ (at point P)} = \frac{\lambda_2}{2\pi\epsilon_0 r_2}$$

$$\vec{E} = \frac{20 \times 10^{-6}}{2\pi\epsilon_0 (20 \times 10^{-2})} (-\hat{j}) \text{ N/C}$$

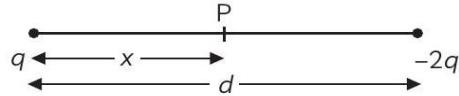
$$E_{net} = \frac{10 \times 10^{-6}}{2\pi\epsilon_0} \left(\frac{1}{0.1} + \frac{2}{0.2} \right) (-\hat{j}) \text{ N/C}$$

$$= 3.6 \times 10^6 (-\hat{j}) \text{ N/C}$$

$$\vec{F}_{net} = q \times \vec{E}_{net}$$

$$\vec{F} = -1.6 \times 10^{-19} \times 3.6 \times 10^6 (-\hat{j}) \text{ N}$$

$$= 5.76 \times 10^{-13} \text{ N} (\hat{j})$$



Explanation: Let P be the required point at a distance x from charge q

$$\therefore \frac{1}{4\pi\epsilon_0} \frac{q}{x} + \frac{1}{4\pi\epsilon_0} \frac{(-2q)}{d-x} = 0$$

$$\frac{1}{x} = \frac{2}{d-x}$$

$$x = \frac{d}{3}$$

\therefore The required point is at a distance $\frac{d}{3}$ from the charge q . (2024)

2. ELECTROSTATIC OF CONDUCTORS, DIELECTRICS AND CAPACITANCE

36. (a) decreases

Explanation: We know electric field between capacitor or plates:

$$E = \frac{\sigma}{\epsilon_0} = \frac{V}{d}$$

Where, d is the distance between the plates.

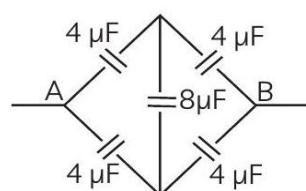
When battery is disconnected, the charge present on capacitor is fixed, i.e., V is constant. Now, when the dielectric is introduced, the electric field becomes.

$$E' = \frac{V}{Kd'}$$

Where, K is dielectric constant which is always > 1 . Hence, electric field decreases.

37. (a) $4\mu F$

Explanation: The given circuit can also be made in the following way.



This is just like the Wheatstone bridge. As the bridge is balanced ($\frac{4}{4} = \frac{4}{4}$), there will be no effect of $8\mu F$ capacitor on the capacitance. Equivalent capacitance is given by

$$\begin{aligned}
 C' &= C + C \\
 &= 2\mu F + 2\mu F \\
 &= 4\mu F
 \end{aligned}$$

38. (a) decreases K times

Explanation: In air the force of attraction between two charges,

$$F_a = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

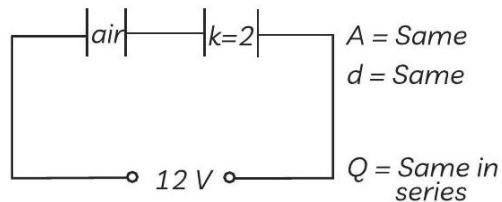
In dielectric medium the force of attraction between two charges is,

$$F_d = \frac{1}{4\pi K\epsilon_0} \frac{q_1 q_2}{r^2} = \frac{F_a}{K}$$

Thus, Force decreases K times.

39. (c) 2: 1

Explanation:



$$\begin{aligned}
 C_x &= \frac{\epsilon_0 A}{d}, C_y = \frac{2\epsilon_0 A}{d} \\
 U_x &= \frac{Q^2}{2C_x}, U_y = \frac{Q^2}{2C_y} \\
 \therefore \frac{U_x}{U_y} &= \frac{C_y}{C_x} = \frac{2C_x}{C_x} = \frac{2}{1}
 \end{aligned}$$

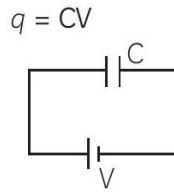
40. (c) $\frac{V}{K}$

Explanation: Given:

Capacitor of capacitance = C Charging voltage = V

Dielectric constant = K

Case 1: When a capacitor is initially charged it acquires charge.



Case 2: When battery is disconnected its charge remains " q ". But when a dielectric slab is introduced within the plates the only parameter that remains constant is the charge " q ".

Hence, ' q' = $CV = C'V$

Since, $C = \epsilon \frac{A}{d}$ in case 1 and $C' = K\epsilon_0 \frac{A}{d}$ in case 2. which means $C = KC$.

$$\begin{aligned} \therefore q &= CV = KCV \\ \Rightarrow V' &= \frac{CV}{KC_0} = \frac{V}{K} \end{aligned}$$

41. (a) $6.0 \times 10^4 C$

Explanation: Given,

$$\begin{aligned} V &= 12 V \\ W &= 7.20 \times 10^5 J \\ V &= \frac{W}{Q} \\ Q &= \frac{W}{V} = \frac{7.20 \times 10^5 J}{12 V} \\ &= 6.0 \times 10^4 C \end{aligned}$$

42. (a) $1\mu F$

Explanation: Energy of a capacitor

$$U = -\frac{1}{2} CV^2$$

[Where V is voltage/potential difference between plates]

Charge in energy = Final energy of capacitor Initial energy of capacitor

$$\begin{aligned} -2 \times 10^{-2} J &= \frac{1}{2} \cdot X \cdot (200)^2 - \frac{1}{2} \cdot (2\mu F) \cdot (200)^2 \\ -2 \times 10^{-2} &= \left(\frac{4 \times 10^4}{2} \right) X - 2\mu F \\ -10^{-6} &= X - 2\mu F \\ X &= 2\mu F - 10^{-6} \\ X &= 2\mu F - 1\mu F = 1\mu F \end{aligned}$$

43. Let a be the radius of a sphere A , Q_A be the charge on the sphere, and C_A be the capacitance of the sphere. Let b be the radius of sphere B , Q_B be the charge on the sphere, and C_B be the capacitance of the sphere. Since the two spheres are connected with a wire, their potential (V) will become equal.

Let E_A be the electric field of sphere A and E_B be the electric field of sphere B . Therefore, their ratio,

$$\frac{E_A}{E_B} = \frac{Q_A}{4\pi\epsilon_0 \times a^2} \times \frac{b^2 \times 4\pi\epsilon_0}{Q_B}$$

$$\frac{E_A}{E_B} = \frac{Q_A}{Q_B} \times \frac{b^2}{a^2}$$

However, $\frac{Q_A}{Q_B} = \frac{C_A V}{C_B V}$

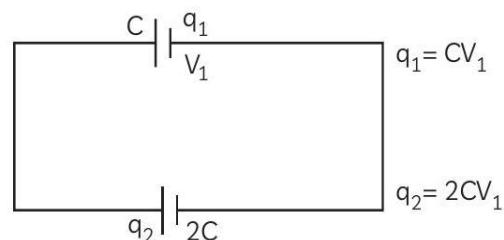
and $\frac{C_A}{C_B} = \frac{a}{b}$

Putting the value of (ii) in (i), we obtain

$$\therefore \frac{E_A}{E_B} = \frac{a}{b} \frac{b^2}{a^2} = \frac{b}{a}$$

Therefore, the ratio of electric fields at the surface is $\frac{b}{a}$.

44.



$$q_1 + q_2 = Q$$

$$q_1 + q_1 = CV$$

$$CV_1 + 2CV_1 = CV$$

$$V_1 = \frac{V}{3}$$

$$q_1 = CV_1 = C \frac{V}{3} = \frac{Q}{3}$$

$$q_2 = 2CV_1 = 2C \frac{V}{3} = \frac{2Q}{3}$$

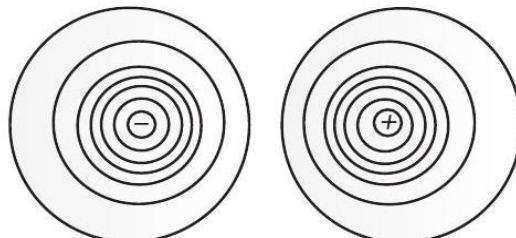
$$\frac{q_1}{q_2} = \frac{1}{2}$$

$$U_1 = \frac{1}{2} CV_1^2 = \frac{1}{18} CV^2$$

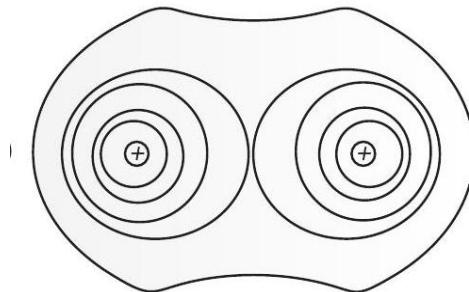
$$U_2 = \frac{1}{9} CV^2$$

$$\frac{U_1}{U_2} = \frac{1}{2}$$

45. (A) (I)



(ii)



(B) Here, $A = 6 \times 10^{-3} \text{ m}^2$,

$$d = 3 \text{ mm} = 3 \times 10^{-3} \text{ m}$$

$$(i) \text{ Capacitance, } C = \epsilon_0 \frac{A}{d}$$

$$\begin{aligned}
 &= \left(\frac{8.85 \times 10^{-12} \times 6 \times 10^{-3}}{3 \times 10^{-3}} \right) \\
 &= 17.7 \times 10^{-12} \text{ F}
 \end{aligned}$$

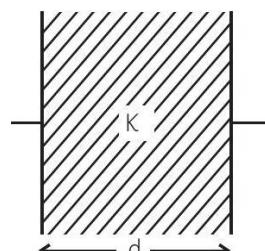
(ii) Charge, $Q = CV = 17.7 \times 10^{-12} \times 100$

$$= 17.7 \times 10^{-10} \text{ C}$$

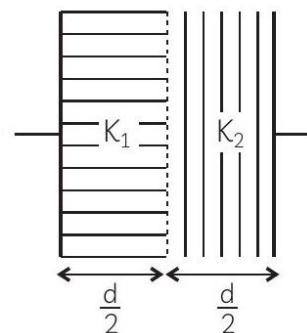
(iii) New charge, $Q' = KQ = 6 \times 17.7 \times 10^{-10}$

$$= 1.062 \times 10^{-8} \text{ C}$$

46.



(Case 1)



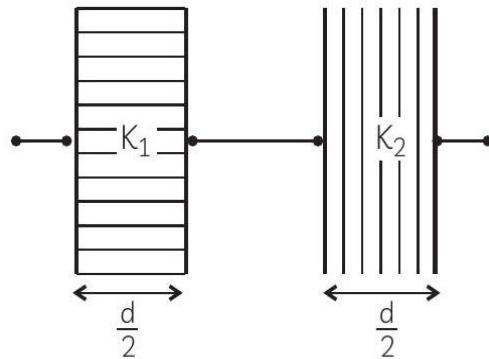
(Case 2)

For Case 1

$$C = \frac{K \epsilon_0 A}{d}$$

For Case 2

We can consider that two capacitors are connected in series as shown



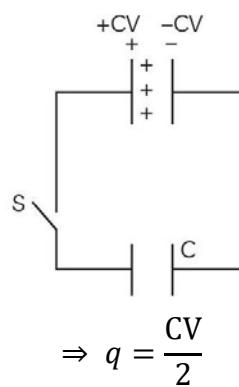
For series combination

$$\begin{aligned}
 \Rightarrow \quad \frac{1}{C} &= \frac{\frac{d}{2}}{K_1 \epsilon_0 A} + \frac{\frac{d}{2}}{K_2 \epsilon_0 A} \\
 \Rightarrow \quad \frac{d}{K \epsilon_0 A} &= \frac{d}{2 \epsilon_0 A} \left(\frac{1}{K_1} + \frac{1}{K_2} \right) \\
 \Rightarrow \quad \frac{1}{K} &= \frac{1}{2} \left(\frac{1}{K_1} + \frac{1}{K_2} \right) \\
 \Rightarrow \quad \frac{1}{K} &= \frac{1}{2} \left(\frac{K_2 + K_1}{K_1 K_2} \right) \\
 \Rightarrow \quad K &= \frac{2 K_1 K_2}{K_1 + K_2}
 \end{aligned}$$

47. When capacitors are linked in parallel with a direct current source, the charging of the capacitor occurs: the plates are charged in accordance with the terminals of the battery, such that the potential difference between the plates equals the terminal potential of the direct current battery.

48. Let charge q be transferred from one capacitor to the other. Then equating potential difference across the two capacitors,

$$\frac{CV - q}{C} = \frac{q}{C}$$



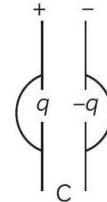
$$\Rightarrow q = \frac{CV}{2}$$

Now, Energy stored in the combination,

$$\text{Initial energy, } U_i = \frac{1}{2} C^2$$

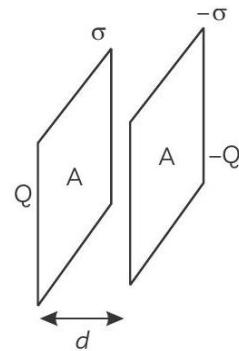
$$U_f = 2 \frac{q^2}{2C} = \frac{C^2}{4}$$

$$CV - q(CV - q)$$



$$\Rightarrow \frac{U_f}{U_i} = \frac{CV^2}{4} \frac{2}{CV^2} = \frac{1}{2}$$

49. (A) Derivation of the expression for the capacitance:



Let the two plates be kept parallel to each other separated by a distance d and crosssectional area of each plate is A . Electric field by a single thin plate

$$E = \frac{\sigma}{2\epsilon_0}$$

Total electric field between the plates

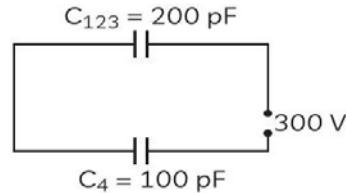
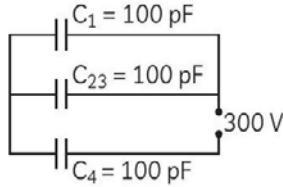
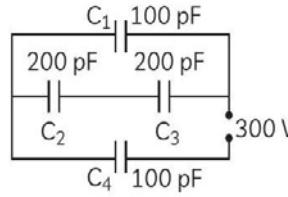
$$E = \frac{\sigma}{\epsilon_0} = \frac{Q}{A\epsilon_0}$$

Potential difference between the plates

$$V = Ed = \left[\frac{Q}{A\epsilon_0} \right] d$$

$$\text{Capacitance, } C = \frac{Q}{V} = \frac{A\epsilon_0}{d}$$

(B)



The equivalent capacitance = $\frac{200}{3}$ pF

$$\begin{aligned}\text{charge on } C_4 &= \frac{200}{3} \times 10^{-12} \times 300 \\ &= 2 \times 10^{-8} \text{ C}\end{aligned}$$

Potential difference across.

$$\begin{aligned}C_4 &= \frac{200 \times 10^{-12} \times 300}{3 \times 100 \times 10^{-12}} \\ &= 200 \text{ V}\end{aligned}$$

Potential difference across C_1

$$\begin{aligned}&= 300 - 200 \\ &= 100 \text{ V}\end{aligned}$$

charge on $C_1 = 100 \times 10^{-12} \times 100$

$$= 1 \times 10^{-8} \text{ C}$$

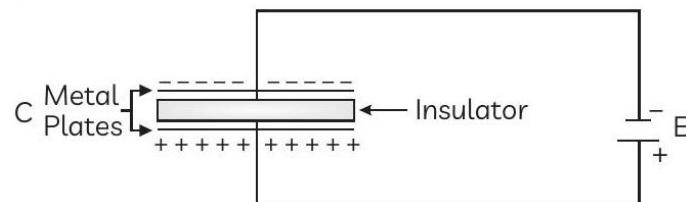
Potential difference across C_2 and C_3 series combination = 100 V potential difference across C_2 and C_3 each

$$= 50 \text{ V}$$

charge on C_2 and C_3 each

$$\begin{aligned} &= 200 \times 10^{-12} \times 50 \\ &= 1 \times 10^{-8} \text{ C} \end{aligned}$$

50. Consider the parallel plate capacitor depicted in the image, which is connected across a D.C. battery. The circuit will conduct electric current. As the charges approach the plate, the insulating gap prevents them from moving any farther; hence, positive charges deposit on one side of the plate and negative charges deposit on the other. As a result, the current flowing through the circuit steadily decreases and ultimately stops until the voltage of the capacitor is exactly equal to but opposite to the voltage of the battery. When a capacitor is connected across a D.C. battery, it charges in this manner.



(A) The electric field between the plates is;

$$E = \frac{V}{d}$$

The distance between plates is doubled, $d' = 2d$

$$E' = \frac{V'}{d'} = \left(\frac{V}{d}\right) \times \frac{1}{2} = \frac{1}{2} \left(\frac{E}{d}\right)$$

Therefore, if the distance between the plates is double, the electric field will reduce to one half.

(B) As the capacitance of the capacitor,

$$C' = \frac{\epsilon_0 K A}{d'} = \frac{\epsilon_0 K A}{2d} = \frac{1}{2} C$$

Energy stored in the capacitor is

$$\begin{aligned} U &= \frac{Q^2}{2C} \\ U' &= \frac{Q^2}{2C'} = \frac{Q^2}{2(1/2)C} \\ &= 2 \left(\frac{Q^2}{2C}\right) = 2U \end{aligned}$$

(from i)

Therefore, when the distance between the plates is doubled, the capacitance reduces to half. Therefore, energy stored in the capacitor becomes double.

51. Let at a particular instant charge on the plate of capacitor be q and its potential difference be $\frac{q}{C}$. If an additional charge dq is given to capacitor plate, work done for it is given by

$$dW = \left(\frac{q}{C}\right) \cdot dq$$

Therefore, whole process of charging from 0 to Q requires a work

$$W = \int_0^Q \frac{qdq}{C} = \frac{1}{C} \left[\frac{q^2}{2} \right]_0^Q = \frac{Q^2}{2C}$$

This work done is stored as the electrostatic potential energy of the charged capacitor Hence, potential energy of charged capacitor

$$U = \frac{Q^2}{2C}$$

But $Q = CV$, where V be the potential difference between the plates of capacitor,

Hence,

$$U = \frac{Q^2}{2C} = \frac{1}{2} QV = \frac{1}{2} CV^2$$

Let initial capacitance of a capacitor be

$$C = \frac{\epsilon_0 A}{d}$$

(A) When spacing between the plates is halved (i.e., $d' = \frac{d}{2}$) and a dielectric medium of $\epsilon_r = 10$ is introduced between the plates, new capacitance of the capacitor will be

$$\begin{aligned} C' &= \frac{\epsilon_0 \epsilon_r A}{d'} = \frac{\epsilon_0 \times 10 \times A}{\left(\frac{d}{2}\right)} \\ &= 20 \frac{\epsilon_0 A}{d} = 20C \end{aligned}$$

$$(B) \text{ Initial electric field } E = \frac{V}{d}$$

As battery remains connected,

$$\text{Hence, } V' = V \text{ but } d' = \frac{d}{2}$$

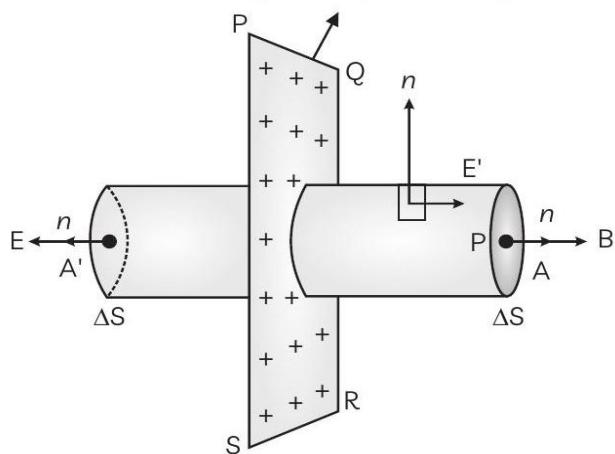
\therefore New electric field,

$$E' = \frac{V'}{d'} = \frac{V}{\frac{d}{2}} = \frac{2V}{d} = 2E$$

52. Let $PQRS$ is an infinitely plane charged sheet and $+\sigma$ be the distribution of charge over the sheet. Let the charge q is bringing from infinity to the distance r from the sheet.

Then, Electric field at the distant r from the sheet

Uniformly infinite phase charge sheet



$$\begin{aligned} \phi &= E \cdot \Delta S \cos \theta \\ \therefore \phi &= E \cdot \Delta S (\theta = 0) \\ \text{and} \quad \phi &= \frac{\sigma}{\epsilon_0} \end{aligned}$$

From equation (i) and (ii)

$$E = \frac{\sigma}{\epsilon_0 \times \Delta S}$$

$$E = \frac{\sigma}{\epsilon_0 \times 2}$$

We know that,

$$\begin{aligned} W &= F \cdot r \\ W &= q \cdot \frac{\sigma}{\epsilon_0 \times 2} r \end{aligned}$$

53. (A) (i) When a conductor is placed in a uniform electric field \vec{E}_0 , electrons present inside conductor drift in a direction opposite to the external electrical field, till the electric field \vec{E}' , produced by drift of free electron with in the conductor just becomes equal and opposite to the external field \vec{E}_0 . Thus, the net electric field $\vec{E}_0 - \vec{E}'$ at any point inside the conductor is zero.

(ii) When a dielectric slab is placed in the electric field \vec{E}_0 , the electrons in atoms or molecules of dielectric get pulled in a direction opposite to the applied electric field. The separation between the charges is such that the force due to the external electric field is just balanced by the restoring force due to internal electric fields in the atom or molecule. The molecules, thus, develop an induced dipole moment and the dielectric is said to be polarised. Let E_p be the internal electric field in the dielectric due to polarisation of charge. Thus, net electric field in the presence of dielectric becomes,

$$\vec{E} = \vec{E}_0 - \vec{E}_p$$

It is observed that,

$$\vec{E} = \frac{\vec{E}_0}{K} - \vec{E}_p = \frac{\vec{E}_0}{K}$$

Where, K is the dielectric constant of the given dielectric, The polarisation vector \vec{p} of a dielectric is defined as the dipole moment developed in the dielectric per unit volume when placed in an external electric field.

Thus, polarisation vector,

$$\vec{p} = \frac{\text{Net dipole moment}}{\text{Volume of dielectric}}$$

For linear isotropic dielectrics, the polarisation vector \vec{p} is found to be directly proportional to external electric field \vec{E}_0 i.e., or $\vec{p} \propto \vec{E}_0$ Hence, χ_e is a constant which is characteristic of a dielectric and is known as the 'electric susceptibility' of given dielectric.

(B) (i) Force experienced by a charge ' q ' when placed in an electric field ' E ' is given by $F = qE$.

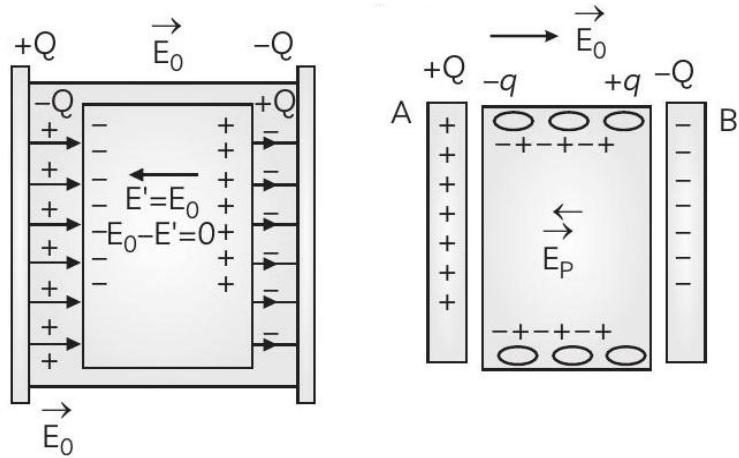
As at centre C of the shell electric field is zero, hence force on the charge at the centre C is zero.

At point A the electric field is due to charge $\frac{Q}{2}$ and Q present on the spherical shell and has a value:

$$E = \frac{1}{4\pi\epsilon_0} \cdot \frac{3Q}{2\pi^2}$$

\therefore Force on the charge $q = (2Q)$ placed at A will be:

$$\begin{aligned} F_A &= qE = (2Q) \left(\frac{1}{4\pi\epsilon_0} \frac{3Q}{2\pi^2} \right) \\ &= \frac{1}{4\pi\epsilon_0} \frac{3Q^2}{x^2} \end{aligned}$$



(ii) The electric flux through the shell

$$\begin{aligned}\phi_E &= \frac{1}{\epsilon_0} \text{ (charge enclosed by the shell)} \\ &= \frac{1}{\epsilon_0} \left(\frac{Q}{2} + Q \right) = \frac{3Q}{2\epsilon_0}\end{aligned}$$

54. When the capacitors are connected in parallel, equivalent capacitance,

$$C_P = C_1 + C_2$$

The energy stored in the combination of the capacitors,

$$\begin{aligned}E_P &= \frac{1}{2} C_P V^2 \\ 0.25 \text{ J} &= \frac{1}{2} (C_1 + C_2) (100)^2 \\ \Rightarrow C_1 + C_2 &= 5 \times 10^{-5} \text{ F}\end{aligned}$$

When the capacitors are connected in series, equivalent capacitance,

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2}$$

The energy stored in the combination of capacitors,

$$\begin{aligned}
E_S &= \frac{1}{2} C_S V^2 \\
E_S &= \frac{1}{2} \frac{C_1 C_2}{5 \times 10^{-5}} (100)^2 \\
\therefore C_S &= \frac{C_1 C_2}{C_1 + C_2} \\
0.45J &= \frac{1}{2} \frac{C_1 C_2}{5 \times 10^{-5}} (100)^2 \\
\Rightarrow C_1 C_2 &= 0.045 \times 10^{-4} \times 5 \times 10^{-5} \times 2 \\
C_1 C_2 &= 4.5 \times 10^{-10} \text{ F} \\
\Rightarrow (C_1 - C_2)^2 &= (C_1 + C_2)^2 - 4C_1 C_2 \\
(C_1 - C_2)^2 &= 25 \times 10^{-10} - 4 \times 4.5 \times 10^{-10} \\
(C_1 - C_2)^2 &= 7 \times 10^{-10} \\
\Rightarrow (C_1 - C_2) &= \sqrt{7 \times 10^{-10}} = 2.64 \times 10^{-5} \\
\Rightarrow C_1 - C_2 &= 2.64 \times 10^{-5} \text{ F}
\end{aligned}$$

On solving eq. (i) and (ii),

$$\begin{aligned}
C_1 &= 35 \mu\text{F} \text{ and } C_2 = 15 \mu\text{F} \\
Q_1 &= C_1 V \\
&= 35 \times 10^{-6} \times 100 \\
\text{we get } &Q_1 = 35 \times 10^{-4} \text{ C} \\
\text{and } &Q_2 = C_2 V \\
&= 15 \times 10^{-6} \times 100 \\
&Q_2 = 15 \times 10^{-4} \text{ C}
\end{aligned}$$

55. (A) Net capacitance = $C_3 = 2 \mu\text{F}$ Others are short-circuited

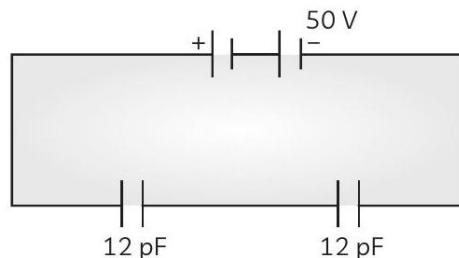
(B) Maximum charge

$$C = q V = 2 \times 10^{-6} \times 5 = 10 \mu\text{C}$$

(C) Total energy

$$E = \frac{1}{2} C V^2 = 0.5 \times 2 \times 10^{-6} \times 25 = 25 \mu\text{J}$$

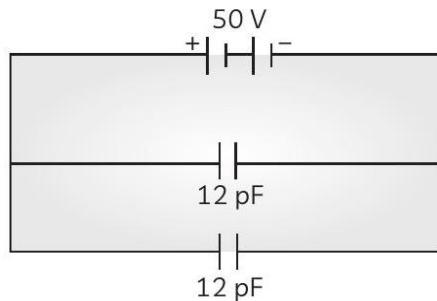
56. Case I:



Equivalent capacitance = 6pF

$$\begin{aligned}
 \text{Energy stored} &= \frac{1}{2} CV^2 \\
 &= \frac{1}{2} \times 6 \times 10^{-12} \times 50 \times 50 \\
 &= 7.5 \times 10^{-9} \text{ J}
 \end{aligned}$$

Case II:



Equivalent Capacitance = 24pF

$$\begin{aligned}
 \text{Energy stored} &= \frac{1}{2} \times 24 \times 10^{-12} \times 50 \times 50 \\
 &= 3 \times 10^{-8} \text{ J}
 \end{aligned}$$

Charge drawn in Case I

$$\begin{aligned}
 Q &= VC \\
 &= 50 \times 6pC \\
 &= 300pC
 \end{aligned}$$

Charge drawn in Case II

$$\begin{aligned}
 &= 2[12 \times 50]pC \\
 &= 1200pC \\
 &= 1.2nC
 \end{aligned}$$

57. (A) In the given circuit C_2 and C_3 are short circuited hence equivalent capacitance is given by,

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_4} + \frac{1}{C_4} + \frac{1}{C_5} = \frac{2}{3} \mu\text{F}$$

(B) $Q = VC$

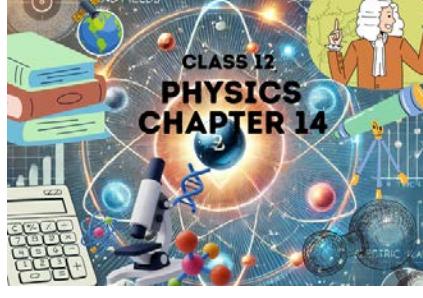
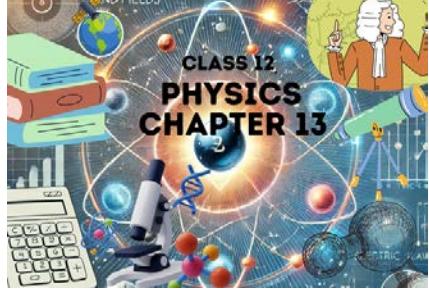
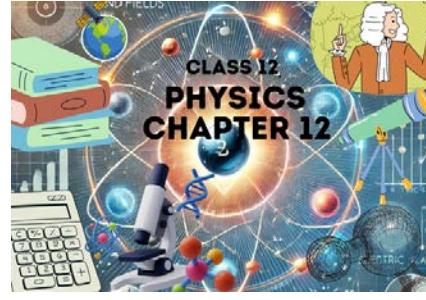
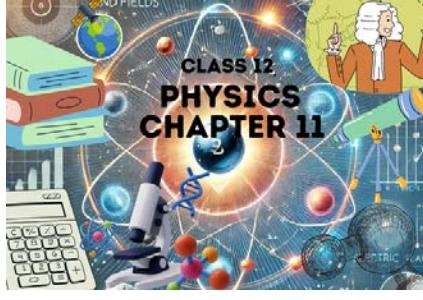
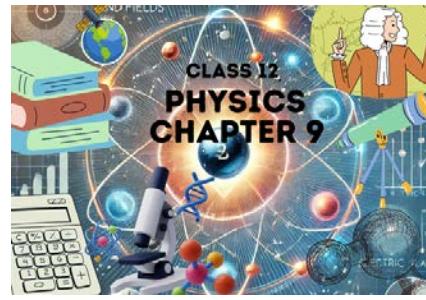
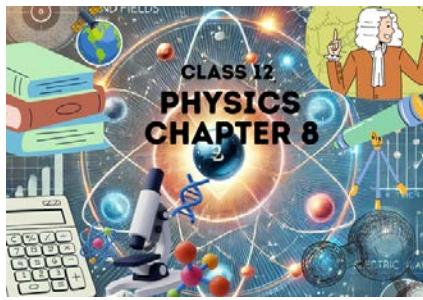
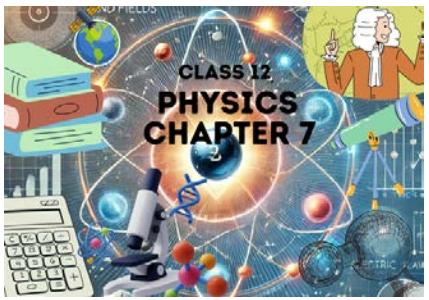
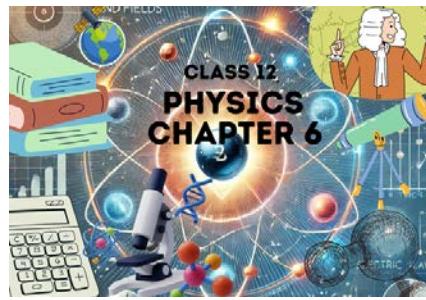
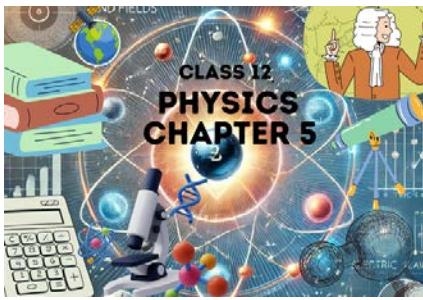
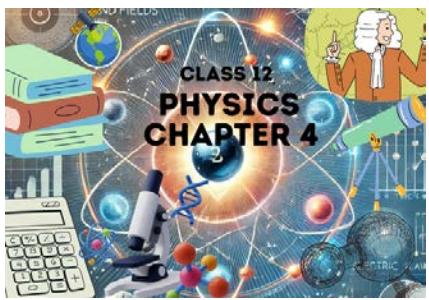
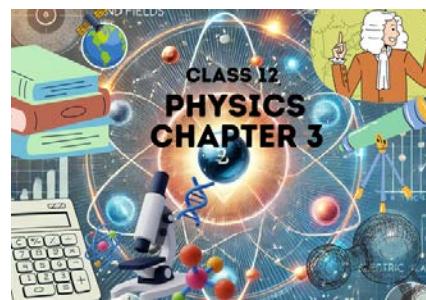
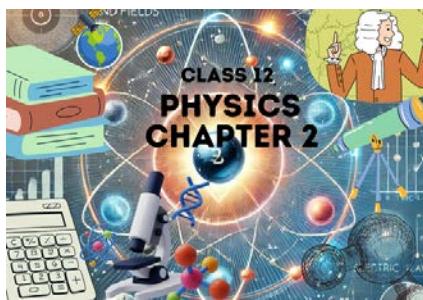
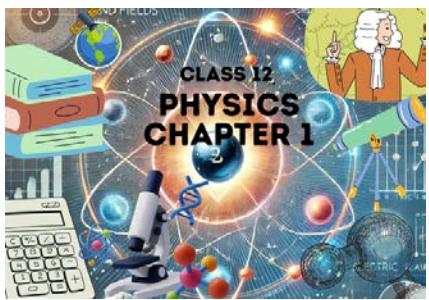
$$\begin{aligned}
 &= 7 \times \frac{2}{3} \mu\text{C} \\
 &= 4.66 \mu\text{C}
 \end{aligned}$$

Energy stored in the Network

$$\begin{aligned}U &= \frac{1}{2} CV^2 \\&= \frac{1}{2} \times \frac{2}{3} \times 10^{-6} \times 7 \times 7 \text{ Joules} \\&= 16.33 \times 10^{-6} \text{ J.}\end{aligned}$$

58. (D) 5.0×10^{-2} J
(2024)

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